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Measurement of the Polarization of the $K\beta 2$ Line of heliumlike V^{21+}

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Abstract

We have measured the polarization of the intercombination line $1s3p\ ^3P_1 - 1s^2\ ^1S_0$, the so called $K\beta 2$ line, in heliumlike V^{21+} using two Bragg crystal spectrometers. The ions were excited in the Lawrence Livermore National Laboratory electron beam ion trap. We find values which are not significantly different from theoretical predictions based on some admixing of the initial state by the hyperfine interaction. In this short paper we present our results.

1. Introduction

Interest in polarization measurements is increasing as polarization spectroscopy is rapidly becoming the standard technique for determining the existence of directed electron beams in laboratory as well as in astrophysical plasmas. The Lawrence Livermore National Laboratory (LLNL) electron beam ion trap EBIT-II facility uses a unidirectional, nearly monoenergetic electron beam to ionize, trap and excite ions. Various electron-ion interactions are investigated by looking at x-ray emission from the trap in a direction that is perpendicular to the electron beam. In EBIT-II, photon emission is anisotropic and the emitted photons are polarized [1], since the electron beam imposes a directionality on the emission process. The Livermore high resolution spectrometers [2] use Bragg crystals to disperse the x-rays and

these crystals have reflectivities which are polarization dependent. For this reason, measured intensities of x-rays produced in an electron beam ion trap must be corrected for polarization [3]. In most cases we use theoretical values for the polarizations of lines whose intensities we wish to correct. The polarizations are calculated using partial cross sections for excitation into magnetic sublevels σ_m . Thus for E1 transitions the polarization is calculated from,

$$P = -\frac{\sigma_1 - \sigma_0}{\sigma_1 + \sigma_0}. \quad (1)$$

We have used the Zhang, Sampson, and Clark [4] code which uses a distorted wave approximation (DWA) to calculate σ_m . These calculations show that for V^{21+} ions at electron energies near the $K\beta 1$ excitation threshold of 6118.3 eV, the polarization of the $K\beta 1$ line is 0.61 [5], and that this value remains nearly constant for energies up to several hundred eV above threshold. This theory also predicts the polarization of the $K\beta 2$ line to be -0.37 for near-threshold excitation. However, experimental measurements described in Ref. [1], found the polarization of the $K\beta 2$ line of Sc^{19+} to have a value near zero. Since Sc and V are adjacent odd-Z nuclei, we expect the polarization of the $K\beta 2$ line of V^{21+} to be near zero also. This is because the vanadium nucleus, like the scandium nucleus, has a nuclear spin of 7/2, and the hyperfine interaction is expected to cause admixing of the upper levels of the intercombination lines of He-like ions of these elements with other levels, and therefore to change the polarization of these lines to near-zero values [1]. The hyperfine interaction does not seem to cause any admixing of the upper levels of the of the resonance lines of these ions, the polarizations of the resonance lines are not affected by the hyperfine interaction.

We define the polarization of an x-ray line emitted at $\vartheta = 90^\circ$ to the electron beam as

$$P = \frac{I_{\parallel}(90^\circ) - I_{\perp}(90^\circ)}{I_{\parallel}(90^\circ) + I_{\perp}(90^\circ)} \quad (2)$$

where I_{\parallel} and I_{\perp} are the intensities of the x-rays polarized parallel and perpendicular to the electron beam, respectively. The actual intensity observed by a spectrometer is given by

$$I^{obs} = R_{\parallel}I_{\parallel}(90^\circ) + R_{\perp}I_{\perp}(90^\circ). \quad (3)$$

Here, R_{\parallel} and R_{\perp} are the integrated reflectivities of the crystal for x-rays polarized parallel and perpendicular to the plane of dispersion. The ratio $R = R_{\perp}/R_{\parallel}$ depends on the Bragg angle θ at which the crystal is set. R varies from $\cos^2(2\theta)$ for mosaic crystals to $|\cos(2\theta)|$ for an ideal crystal. Values of R have been tabulated by Henke, Gullickson, and Davis [6].

The two crystal method for measuring polarization has been described elsewhere [7]. The ratio of the intensities of two lines, $K\beta 1$ and $K\beta 2$ measured by two crystals, say Si and LiF are given by

$$\frac{I^2}{I^1} \Big|_{\text{Si}} = \frac{I_{\parallel}^2 + R_{\text{Si}} I_{\perp}^2}{I_{\parallel}^1 + R_{\text{Si}} I_{\perp}^1} \quad (4)$$

and

$$\frac{I^2}{I^1} \Big|_{\text{LiF}} = \frac{I_{\parallel}^2 + R_{\text{LiF}} I_{\perp}^2}{I_{\parallel}^1 + R_{\text{LiF}} I_{\perp}^1}, \quad (5)$$

where we have assumed that the two lines are close to each other and that R is the same for the Bragg angles spanned by the two lines. We combine the equations 2, 4, and 5 to obtain an expression for the polarization P_2 of $K\beta 2$ in terms the polarization P_1 $K\beta 1$,

$$P_2 = \frac{\frac{I^2}{I^1} \Big|_{\text{Si}} (1 + R_{\text{Si}} \frac{1-P_1}{1+P_1})(R_{\text{LiF}} + 1) - \frac{I^2}{I^1} \Big|_{\text{LiF}} (1 + R_{\text{LiF}} \frac{1-P_1}{1+P_1})(R_{\text{Si}} + 1)}{\frac{I^2}{I^1} \Big|_{\text{Si}} (1 + R_{\text{Si}} \frac{1-P_1}{1+P_1})(R_{\text{LiF}} - 1) - \frac{I^2}{I^1} \Big|_{\text{LiF}} (1 + R_{\text{LiF}} \frac{1-P_1}{1+P_1})(R_{\text{Si}} - 1)}. \quad (6)$$

We have used the values $R_{\text{LiF}} \sim 0$ and $R_{\text{Si}} = 0.44$, these values are appropriate for an ideal crystals.

2. Measurement and Result

We have used the LLNL EBIT-II electron beam ion trap to measure the polarization of the $K\beta 2$ line emitted by heliumlike V^{21+} . The electron beam energy was initially set at 8 kV for a few milliseconds to produce mainly the heliumlike charge state. It was then switched to 6.6 kV to excite the $K\beta 1$ and $K\beta 2$ lines directly. With this excitation energy (which is just above threshold for direct excitation of $K\beta 1$), we expect that direct excitation is the main mechanism for line formation, in particular we do not expect the upper levels of these

lines to be fed by cascades. The polarizations of the lines are therefore not expected to be modified by cascades.

We have used two EBIT high-resolution spectrometers [2], which were configured in von Hámos geometry, and which both had a plane of dispersion perpendicular to the electron beam. For one spectrometer we used a LiF(220) crystal, with a 2d spacing of 2.848 Å, bent to a radius of 30 cm, and set at a nominal Bragg angle of 45°. This spectrometer had a resolving power of $\lambda/\Delta\lambda = 2500$. In this configuration, the spectrometer has zero quantum efficiency for I_{\perp} , and the signal depends on I_{\parallel} only. For the second spectrometer we used a Si(220), which has a 2d spacing of 3.840 Å, and was bent to a radius of 30 cm. This crystal was set at a nominal Bragg angle of 31.6°, for a resolving power of $\lambda/\Delta\lambda = 2500$. Figure 1 shows the spectra accumulated by the two spectrometers over the same period of time. The intensities of the lines recorded by the LiF(220) spectrometer at a Bragg angle of 45°, are much lower than those recorded by the Si(220) spectrometer. Part of the reason for this is that the former crystal has zero reflectivity for x-rays that polarized perpendicular to the electron beam.

For each spectrum, we have fitted the lines to Gaussian profiles to obtain relative intensities. We inserted the fitted intensities into Eq. 6 and use the theoretical value of 0.61 for the polarization of $K\beta_1$. As a result, we find a polarization of -0.1 ± 0.2 for the $K\beta_2$ line. The errors in this result come from the fitting procedure, and also from taking into account some perpendicular motion for EBIT electrons. The result is consistent with the expectation that the polarization of the $K\beta_2$ line nearly vanishes because of the hyperfine interaction admixing the upper level of the intercombination line with other levels. The measured value is not consistent with the value of -0.37 predicted by the DWA to be the polarization of the $K\beta_2$ line in the absence of the hyperfine interaction.

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5. Figures

Fig. 1. $K\beta$ spectra of heliumlike V^{21+} excited in the Lawrence Livermore National Laboratory electron beam ion trap EBIT-II. The upper spectrum was accumulated with a Si(220) crystal set at a nominal Bragg angle of 31.63° , while the lower spectrum was obtained with a LiF(220) crystal set at a nominal Bragg angle of 45° .

